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Project Check-in Report

Production Scheduling at Falcon Die Casting

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Executive Summary:

Falcon Die Casting (FDC), an Ohio-based automobile manufacturer, has patented a high volume die casting method using traditional machines. They received a bulk order for five key die cast items used in most automobiles. The client estimates demand for the next 12 weeks, with demand beyond week 2 tentative and likely to change based on prior sales.

FDC produces five machines, each capable of producing a subset of parts. The design capacity can meet long-term customer demand for five parts, but its effective capacity can only satisfy demand if a significant percentage of items are not quality demanded. FDC's yield factors predict the proportion of parts meeting customer quality specifications, and Table-2 provides production rates for five parts in five different machines.

Production operates from Monday to Friday with three eight-hour shifts, resulting in 120 hours per week. Weekends are used for maintenance and experimentation, with a maximum overtime of 48 hours per week. Machine setup times range from 8 to 24 hours, and production of parts may need to be scheduled multiple times.

The production manager, Tom Kelly, aims to schedule production optimally, ensuring employees are paid and half for overtime. He aims to meet the demand for 5 parts with the least overtime. Tom is also concerned about the impact of the company's policy not carrying finished goods or inventory from week to week and wants to perform routine maintenance on weekends without disrupting machine setups.

1. INTRODUCTION

Falcon Die Casting Company (FDC) has earned a lucrative long-term contract with a major automobile manufacturer for five critical die-cast components. However, meeting this demand offers distinct obstacles because of shifting consumer forecasts, limited production capacity, and internal operational constraints. The research presented in this article evaluates FDC's present production system and identifies major areas for improvement, focusing on scheduling optimization and minimizing overproduction. The customer provides FDC with preliminary 12-week demand predictions, with flexibility beyond Week 2 based on real-time auto sales. While their five die-casting machines have the design capacity to handle this demand, their effective capacity currently needs to be improved due to high defect rates.

1.2Challenges and Issues:

Production operates Monday through Friday with three shifts, offering 120 hours of regular time per machine. Weekends are reserved for maintenance and experimentation, with additional overtime production available if necessary. However, current scheduling practices are time-consuming and suboptimal, often leading to:

- High defect rates: A high percentage of manufactured parts fail to fulfil quality standards, restricting effective capacity and perhaps leading to stockouts.
- Uncertainty in demand: Demand in Week 2 and beyond is speculative, making planning and resource allocation problematic.
- Weekends: Used for maintenance and experimentation, diminishing available production time and necessitating potential overtime.

1.2.1 Scheduling:

- Inefficient: The current trial-and-error approach frequently results in unnecessary setups, unequal machine workload, and wasteful overtime.
- Lack of optimization: No guarantee that the final schedule assigns parts to machines in the most efficient and cost-effective way.

1.2.2 Inventory

- No buffer: Strict policy of not holding finished goods inventory from week to week restricts production flexibility and limits ability to adjust to demand fluctuations.

1.2.3 Additional challenges:

- Setup times: Setting up machines for different parts is time-consuming (8-24 hours).
- Limited overtime: Employees are paid time and a half for overtime, making it a costly option.

2. Data:
2.1 Input Data

The tasks involve optimizing production efficiency and cost-effectiveness to meet demand for five specific parts while minimizing overtime costs. The goal is to strategically schedule tasks to achieve production demands with minimal overtime, ensuring operational efficiency and financial savings.

WEEK	PART 1	PART 2	PART 3	PART 4	PART 5
1	3500	3000	4000	4000	2800
2	3000	2800	4000	4300	2800
3	3000	2000	4000	3500	3000
4	3000	3000	4000	3800	2800
5	3000	3000	4000	4000	2800
6	3500	2500	4000	3800	2500
7	3500	2500	3800	4000	2500
8	3300	3400	3700	4200	2500
9	3300	3400	0	4500	3000
10	3200	3000	0	4500	3000
11	4500	4000	5000	5000	3800
12	3000	2800	4000	4300	2800

Table 1: Projected Demand

An overview of the expected demand for each week throughout the given period is shown in Table 1. The customer provides FDC an initial estimate of the expected demand for the next 12 weeks, with the understanding that the demand for weeks beyond the second week is tentative and dependent on the variations in auto sales observed in the preceding weeks.

	Part 1	Part 2	Part 3	Part 4	Part 5
Machine1	40	0	0	60	0
Machine 2	35	25	0	0	0
Machine 3	0	30	0	0	45
Machine 4	0	35	50	0	0
Machine 5	0	0	0	60	50
Yield	0.6	0.55	0.75	0.65	0.6

Table 2: Production Rates (Units/hr)

Industrial engineers at FDC have developed yield factors aimed at predicting the proportion of parts that conform to quality specifications. The given table provides details of production rate associated with each part on specific machines, along with corresponding yield factors. As an illustration, dedicating 3 hours to the production of Part 1 on Machine 1 results in the creation of 72 items that meet the specified quality standards. These yield factors are instrumental in guiding production planning

	Part 1	Part 2	Part 3	Part 4	Part 5
Machine1	8	0	0	8	0
Machine 2	10	8	0	0	0
Machine 3	0	10	0	0	24
Machine 4	0	8	12	0	0
Machine 5	0	0	0	8	20

Tabel 3: Part Setup Times (hours)

The given table outlines the duration required to set up each machine to produce various parts, spanning a range of 8 to 24 hours. It is crucial to note that these setup times are independent of the specific production order, signifying that the time allocated for machine setup remains constant regardless of the sequence or quantity of parts being produced.

2.2Data use and Limitations-

- **Excess Defective Rate:** Monitoring yield factors and adjust production schedules as needed based on real-time quality data.
- **Uncertain Demand Beyond Week 2:** Developing flexible production plans that can adapt to changing demand patterns.
- **Inefficient Scheduling:** Implementing a data-driven scheduling optimization algorithm to assign parts to machines efficiently, considering setup times, production rates, and demand.
- **No Finished Goods Inventory:** Analysing the cost-benefit trade-off of carrying a small buffer inventory of finished goods to mitigate the risk of stockouts and overtime. Exploring alternative inventory management strategies, such as just-in-time delivery or consignment stock, to improve flexibility and reduce inventory costs.
- **Further Limitations:** Machine specialization: While FDC's current machines are efficient for specific parts, consider diversifying capabilities or investing in more flexible machines to adapt to future demand changes.

2.3Further data Analysis-

- Different machine efficiencies can result in individual machine production costs.
- It is not explained whether every machine is provided with individual support personnel, or all machines are available with single personnel.
- It is not mentioned whether more than one machine can be simultaneously setup or not.
- Also, whether machines were setup initially or not is not clarified.

3. Mathematical Formulation:

Question 2:

Objective Function: The objective function is to minimize the total overtime hours of all machines across respective weeks.

Minimize Z= $\sum_{i=1,\,t=1}^{i=5,\,t=12}(O_{it})$

Decision Variable:
Machine Runtime, Binary Variable (Boolean Table)

Description:
Machine Runtimes (X_ijt):
These are variables representing the runtime of machine j for producing part i in week t.

Overtime Maximum (OT_Max):
this is a decision variable representing the maximum overtime among all the 5 machines.

Binary Variable:
This is a binary variable, often denoted by a Boolean table. It indicates that the machine is ON or OFF.

Constraints:
Demand Constraint:
The production rates, yield factors, and machine runtimes are constrained by the demand for each part in each week. The other side of the equation ensures that the total production meets the demand for each part in each week.
$\sum_{i=1\,,j=1\,,\ t=1}^{i=5,j=5\ \ t=12} X_{ijt}\ *\ \ Production\ Rate_{ij}\ \ *\ \ Yeild\ Factor_{ij}\ \ = Demand_{jt}.$
(Demand Constraint)

Time Availability Constraint:
The total time for machine runtimes, overtime, and setup time for each part and machine should not exceed the available time of weekdays (120 hours) plus overtime (48 hours).

$\sum_j X_{ijt}$ + O_{it} + $Setup\ Time_{ij}$ <= 120 (Availability per week) + 48 (Overtime).
(Time Availability Constraint)

3. **Maximum Overtime Constraint:**
The maximum allowable overtime for any given week (O_it) is constrained to be between 0 and 48 hours.
$0 \leq O_{it} \leq 48$
(Maximum Overtime Constraint)

where j = 1,2,3,4,5 (Machines)
i = 1,2,3,4,5 (Parts)
t = 1 - 12 (Weeks)

Question 3:

Objective Function: The objective function is to minimize the maximum overtime of all 5 machines.
Minimize *Z* = OT_{Max}

Decision Variable:
Machine Runtime, OT_{Max}, Binary Variable (Boolean Table)

Constraints:
$\sum_{i=1\,,j=1\,,\,t=1}^{i=5,j=5\quad t=12} X_{ijt} \,*\, Production\ Rate_{ij} \,*\, Yeild\ Factor_{ij} = Demand_{jt}.$
(Demand Constraint)

$\sum_j X_{ijt}$ + O_{it} + $Setup\ Time_{ij}$ <= 120 (Availability per week) + 48 (Overtime).
(Time Availability Constraint)

0 ≤ O_{it} ≤ 48
(Maximum Overtime Constraint)

Additional Constraint with LP Model in Question 2:
$OT_j \leq OT_{Max}$ (Each Machine Overtime must be less than or equal to max overtime)

This constraint ensures that the overtime of each machine must be less than or equal to the predefined maximum value.

where j = 1,2,3,4,5 (Machines)
i = 1,2,3,4,5 (Parts)
t = 1 - 12 (Weeks)

Question 4:

Objective Function: The objective of this problem is to minimize the total cost, represented by the objective function Z. The cost consists of 2 parts:

Minimize *Z* =($\sum_{j=1}^{5} OT_j$ * 30) + (OT_{Max} * 40)

Regular Overtime Costs ($\sum_{j=1}^{5} OT_j$):
The first term in the objective function represents the regular overtime costs for each machine (OT_j) multiplied by a cost factor of $30.

Cost to support personnel (OT_{Max}):
The second term represents the maximum overtime cost needed for the support personnel. multiplied by a cost factor of $40.

Decision Variable:
Machine Runtime, OT_{Max}, Binary Variable (Boolean Table)

Constraints:
$\sum_{i=1\,,j=1\,,\,t=1}^{i=5,j=5\quad t=12} X_{ijt} \,*\, Production\ Rate_{ij} \,*\, Yeild\ Factor_{ij} = Demand_{jt}.$
(Demand Constraint)

$\sum_j X_{ijt}$ + O_{it} + $Setup\ Time_{ij}$ <= 120 (Availability per week) + 48 (Overtime).

(Time Availability Constraint)

0 ≤ O_{it} ≤ 48
(Maximum Overtime Constraint)

$OT_j \leq OT_{Max}$ **(Each Machine Overtime must be less than or equal to max overtime)**

where j = 1,2,3,4,5 (Machines)
i = 1,2,3,4,5 (Parts)
t = 1 - 12 (Weeks)

Question 5:
The objective function, decision variable and constraints are similar as Question 2.

- **Discussing Various Models**

The are 2 models used in the problem are:

1. **Trial and error Model:** The success of a trial-and-error approach depends on the company's ability to learn and adapt quickly from the data it generates. While it can be effective for smaller-scale problems, it might not be the most efficient solution for FDC's complex production environment. Exploring alternative approaches in conjunction with trial and error could lead to faster and more sustainable improvements.

2. **Linear Programming Model:** A linear programming (LP) model can help FDC optimize its weekly production plans by considering multiple constraints and maximizing profit or minimizing costs. A linear programming model can be a valuable tool for FDC to optimize its production planning and improve efficiency, profitability, and customer satisfaction.

4. Implementation:

Problem 1. Using a trial-and-error approach, propose a production schedule for meeting the first week's demand for the five parts.

➢ **Steps to find the solution are as follows:**

- **Step 1**

At the start of the shift, our decision was to initiate the production of part 1 using both machines 1 and 2, produce part 5 utilizing machines 3 and 5, and manufacture part 3 on machine 4. This was the chosen approach for commencing operations across all the machines.

- **Step 2**

It is very difficult to assume the values of total machine run time for part 1, as it's made by 2 machines i.e. MC-1 & MC-2. So we ran a python code for the following to calculate the possible values to run machine 1 and 2 together to meet the demand of part 1 in week 1 which is 3500.
With the help of the below python code we have generated values for the runtime of Machine 1 and Machine 2 for the production of part 1.

Code for Machine 1 and Machine 5

```
# Define the equation: 24x + 21y = 3500
# We want to solve for y given values of x from 0 to 111
# Define the constants from the equation
# x= Machine 1 runtime
# y= Machine 2 runtime
a = 24
b = 21
c = 3500
# List to store the values of y for different values of x
y_values = []
# Loop through values of x from 0 to 111
for x in range(121):
  # Solve for y using the equation: 24x + 21y = 3500
  y = (c - a * x) / b
  y_values.append(y)
# Print the values of y for each x
for x, y in enumerate(y_values):
 if(y<=110):
  if(x>y):
   print(f"MC1 = {x}, MC2 = {y}")
```

The above code generated the below list of values:

MC1 = 78, MC2 = 77.52380952380952	MC1 = 78	MC2 = 77.52380952380952
MC1 = 79, MC2 = 76.38095238095238	MC1 = 79	MC2 = 76.38095238095238
MC1 = 80, MC2 = 75.23809523809524	MC1 = 80	MC2 = 75.23809523809524
MC1 = 81, MC2 = 74.0952380952381	MC1 = 81	MC2 = 74.0952380952381
MC1 = 82, MC2 = 72.95238095238095	MC1 = 82	MC2 = 72.95238095238095
MC1 = 83, MC2 = 71.80952380952381	MC1 = 83	MC2 = 71.80952380952381
MC1 = 84, MC2 = 70.66666666666667	MC1 = 84	MC2 = 70.66666666666667
MC1 = 85, MC2 = 69.52380952380952	MC1 = 85	MC2 = 69.52380952380952
MC1 = 86, MC2 = 68.38095238095238	MC1 = 86	MC2 = 68.38095238095238
MC1 = 87, MC2 = 67.23809523809524	MC1 = 87	MC2 = 67.23809523809524
MC1 = 88, MC2 = 66.0952380952381	MC1 = 88	MC2 = 66.0952380952381
MC1 = 89, MC2 = 64.95238095238095	MC1 = 89	MC2 = 64.95238095238095
MC1 = 90, MC2 = 63.80952380952381	MC1 = 90	MC2 = 63.80952380952381
MC1 = 91, MC2 = 62.666666666666664	MC1 = 91	MC2 = 62.666666666666664
MC1 = 92, MC2 = 61.523809523809526	MC1 = 92	MC2 = 61.523809523809526
MC1 = 93, MC2 = 60.38095238095238	MC1 = 93	MC2 = 60.38095238095238
MC1 = 94, MC2 = 59.23809523809524	MC1 = 94	MC2 = 59.23809523809524
MC1 = 95, MC2 = 58.095238095238095	MC1 = 95	MC2 = 58.095238095238095
MC1 = 96, MC2 = 56.95238095238095	MC1 = 96	MC2 = 56.95238095238095
MC1 = 97, MC2 = 55.80952380952381	MC1 = 97	MC2 = 55.80952380952381
MC1 = 98, MC2 = 54.666666666666664	MC1 = 98	MC2 = 54.666666666666664
MC1 = 99, MC2 = 53.523809523809526	MC1 = 99	MC2 = 53.523809523809526
MC1 = 100, MC2 = 52.38095238095238	MC1 = 100	MC2 = 52.38095238095238
MC1 = 101, MC2 = 51.23809523809524	MC1 = 101	MC2 = 51.23809523809524
MC1 = 102, MC2 = 50.095238095238095	MC1 = 102	MC2 = 50.095238095238095
MC1 = 103, MC2 = 48.95238095238095	MC1 = 103	MC2 = 48.95238095238095
MC1 = 104, MC2 = 47.80952380952381	MC1 = 104	MC2 = 47.80952380952381
MC1 = 105, MC2 = 46.666666666666664	MC1 = 105	MC2 = 46.666666666666664
MC1 = 106, MC2 = 45.523809523809526	MC1 = 106	MC2 = 45.523809523809526
MC1 = 107, MC2 = 44.38095238095238	MC1 = 107	MC2 = 44.38095238095238
MC1 = 108, MC2 = 43.23809523809524	MC1 = 108	MC2 = 43.23809523809524
MC1 = 109, MC2 = 42.095238095238095	MC1 = 109	MC2 = 42.095238095238095
MC1 = 110, MC2 = 40.95238095238095	MC1 = 110	MC2 = 40.95238095238095
MC1 = 111, MC2 = 39.80952380952381	MC1 = 111	MC2 = 39.80952380952381
MC1 = 112, MC2 = 38.666666666666664	MC1 = 112	MC2 = 38.666666666666664
MC1 = 113, MC2 = 37.523809523809526	MC1 = 113	MC2 = 37.523809523809526
MC1 = 114, MC2 = 36.38095238095238	MC1 = 114	MC2 = 36.38095238095238
MC1 = 115, MC2 = 35.23809523809524	MC1 = 115	MC2 = 35.23809523809524
MC1 = 116, MC2 = 34.095238095238095	MC1 = 116	MC2 = 34.095238095238095
MC1 = 117, MC2 = 32.95238095238095	MC1 = 117	MC2 = 32.95238095238095
MC1 = 118, MC2 = 31.80952380952381	MC1 = 118	MC2 = 31.80952380952381
MC1 = 119, MC2 = 30.666666666666668	MC1 = 119	MC2 = 30.666666666666668
MC1 = 120, MC2 = 29.523809523809526	MC1 = 120	MC2 = 29.523809523809526

- **Step 3:**The values shown in red are rejected because the setup time for MC1 for both parts and the runtime for MC1 exceeds the maximum number of hours, which is 120. Ex: 8+105+8+.. > 120

- **Step 4:** We chose the value that is highlighted in green as by doing trial and error analysis we found that the median value is the most convenient as we were getting least overtime and it represents the midpoint for all possible combinations of running MC1 and MC2 together.

- **Step 5:**
  We followed the same procedure of MC3 and MC5 as its producing part 5.

- **Code for Machine 3 and Machine 5:**

```
# Define the equation: (45z + 50v) * 0.60 = 2800
# We'll solve for 'z' for different values of 'v'
def solve_for_z(v):
   return (2800 - 30 * v) / 27
# Iterate over values of 'v' from 1 to 96
for v in range(1, 121):
   z = solve_for_z(v)
   if(v>z):
      if(z>=0):
        print(f'MC5 = {v}, MC3 = {z:.2f}')
```

The above code generated the below list of values:

MC5 = 50, MC3 = 48.15
MC5 = 51, MC3 = 47.04
MC5 = 52, MC3 = 45.93
MC5 = 53, MC3 = 44.81
MC5 = 54, MC3 = 43.70
MC5 = 55, MC3 = 42.59
MC5 = 56, MC3 = 41.48
MC5 = 57, MC3 = 40.37
MC5 = 58, MC3 = 39.26
MC5 = 59, MC3 = 38.15
MC5 = 60, MC3 = 37.04
MC5 = 61, MC3 = 35.93
MC5 = 62, MC3 = 34.81
MC5 = 63, MC3 = 33.70
MC5 = 64, MC3 = 32.59
MC5 = 65, MC3 = 31.48
MC5 = 66, MC3 = 30.37
MC5 = 67, MC3 = 29.26
MC5 = 68, MC3 = 28.15
MC5 = 69, MC3 = 27.04
MC5 = 70, MC3 = 25.93
MC5 = 71, MC3 = 24.81
MC5 = 72, MC3 = 23.70
MC5 = 73, MC3 = 22.59
MC5 = 74, MC3 = 21.48
MC5 = 75, MC3 = 20.37
MC5 = 76, MC3 = 19.26
MC5 = 77, MC3 = 18.15
MC5 = 78, MC3 = 17.04
MC5 = 79, MC3 = 15.93
MC5 = 80, MC3 = 14.81
MC5 = 81, MC3 = 13.70
MC5 = 82, MC3 = 12.59
MC5 = 83, MC3 = 11.48
MC5 = 84, MC3 = 10.37
MC5 = 85, MC3 = 9.26
MC5 = 86, MC3 = 8.15
MC5 = 87, MC3 = 7.04
MC5 = 88, MC3 = 5.93
MC5 = 89, MC3 = 4.81
MC5 = 90, MC3 = 3.70
MC5 = 91, MC3 = 2.59
MC5 = 92, MC3 = 1.48
MC5 = 93, MC3 = 0.37

Rejecting the red values and taking the value marked in green for the production of Part 5.

- **Step 6:** Calculating for Part 3 from Machine 4, we performed a linear equation 4000/(50*0.75). Here, 4000 is the demand, 50 hours denotes the production rate of part 3 on machine 4, and 0.75 represents the yield factor. Hence, by doing the procedure, the total overtime value of 106.7 comes as an output.

- **Step 7:** By inserting certain values of all parameters of Part 1 and part 5 in the excel spreadsheet, we were left with the possible values of Part 2 in Machine 3, 4 & 5, and Part 4 in machine 1&2, to meet the production requirements made by the client.

- **Step 8:** By doing and inputting values of the machine for their following parts by trial-and-error method, we came up with the values that are highlighted in Green. And from these values we infer that the minimum overtime for machines in Week 1 is 165.41.

Machine Runtime	Part 1	Part 2	Part 3	Part 4	Part 5	Total time to produce	Total Setup Time	Total Avl time (Mon -Fri)	Overtime Hours (Sat & Sun)	Total Production Hours Available	Total time to produce + Total Setup time	Total Overtime
Machine 1	89	0	0	56.45	0	145.45	16.00	120	48	168	161.45	41.45
Machine 2	64.95238	76	0	0	0	140.95	18.00	120	48	168	158.95	38.95
Machine 3	0	90	0	0	24.81	114.81	34.00	120	48	168	148.81	28.81
Machine 4	0	24.42	106.66	0	0	131.08	20.00	120	48	168	151.08	31.08
Machine 5	0	0	0	46	71	117.12	28.00	120	48	168	145.12	25.12
						649.41					765.41	165.41

Problem 2: Develop a linear programming model to determine the optimum production schedule that minimizes the total machine hours of overtime needed to meet the weekly customer demand. Assume that the weekend preventive maintenance effectively resets the machines so that new setups are required to start production each week. Note that in this scenario any remaining production time that is insufficient to setup for a new part, is simply lost. This is a consequence of the maintenance process and the company policy of not carrying any inventory between weeks.

- **Equations:**

i= number of machines
j= number of parts
t= number of weeks
X_{ijt}= Total Production of Machine 'i' for part 'j' in week 't' in hours
$Production\ Rate_{ij}$ = Individual production rate of machine 'i' for part 'j' in hours
$Yeild\ Factor_{ij}$ = Percentage of successful production in machine 'i' for part 'j'
$Demand_{jt}$ = Total demand needed for part 'j' in week 't'

- **Objective Function:** To minimize the overtime (in hours) of Machine 'i' in week 't'

O_{it}= Overtime of machine 'i' in week 't'
Minimize Z= $\sum_{i=1,t=1}^{i=5,t=12}(O_{it})$

Constraints:

- **Demand constraint-** The demand constraint should be equal to the total production rate times by the yield factor and production rate of machine 'i' in part 'j' in week 't'

$$\sum_{i=1\,,j=1\,,t=1}^{i=5,j=5\ \ t=12} X_{ijt} * \ Production\ Rate_{ij} \ * \ Yeild\ Factor_{ij} * = Demand_{jt}$$

- **Time Availability-** The summation of production rate, overtimes and setup times of machine i in part j in week t should be less than equal to 168 (120- total production hours available in a week, 48- total number of overtime available in hours in a week).

$\sum_j X_{ijt} + O_{it} + Setup\ Time_{ij}$ <= 120 (Availability per week) + 48 (Overtime)

- **Maximum Overtime:** The overtime of machine 'i' in week 't' should be greater than equal to 0 and less than equal to the maximum overtime available i.e. 48hours.

$0 \leq O_{it} \leq$ Maximum Overtime

- **Steps to find the solution are as follows:**
  - **Step-1:** At the commencement of the shift, the decision was made to begin Week 1 production to meet the demands of all parts using all machines. Hence, **Table 8** was created with all the required demands.

Week	Part 1	Part 2	Part 3	Part 4	Part 5
1	3500	3000	4000	4000	2800

Table 8: Demands of units per part

  - **Step-2:** We discovered that each machine produces two parts, therefore we built a basic setup schedule where each machine is used for production for first part and the second part in Setup Time (1) and Setup Time (2) respectively which represents whether the machine has been used(setup time) or not(0) for the production of the respective part. The table for each machine is represented in table 9 and in table 9 it is mentioned that by which machine number which parts are produced for simplification.

Machine Number	Part 1	Part 2	Part 3	Part 4	Part 5	Setup Time (1)	Setup Time (2)	Total Setup Time (1+2)
Machine 1	8	0	0	8	0	8	8	16
Machine 2	10	8	0	0	0	10	0	10
Machine 3	0	10	0	0	24	10	0	10
Machine 4	0	8	12	0	0	8	12	20
Machine 5	0	0	0	8	20	0	20	20

Table 9: Setup Times of parts per machines

Machine number	Parts Produced
Machine 1	Part 1 & Part 4
Machine 2	Part 1 & Part 2

Machine 3	**Part 2 & Part 5**
Machine 4	**Part 2 & Part 3**
Machine 5	**Part 4 & Part 5**

Table 10: Parts produced by following Machines

- **Step-3: -** After mentioning setup times for individual parts and machines (mentioned in Table 9 and Table 10), a separate dataset table justifying Machine Run time (Table 11) was created, where every machine time signifies run time per part per machine

Total Time Machine Run	Part 1	Part 2	Part 3	Part 4	Part 5	Total time to produce
Machine 1	0	0	0	0	0	0
Machine 2	0	0	0	0	0	0
Machine 3	0	0	0	0	0	0
Machine 4	0	0	0	0	0	0
Machine 5	0	0	0	0	0	0
						0.00

Table 11: Machine Run Time

- **Step 4** Now, we have implemented excel Solver Feature and entered some necessary constraints to get desired machine run time and operating conditions. Along with the constraints, we must set objective function to Minimum because as mentioned in question, it is required to minimize the total overtime and select simplex LP as our solving method.

➢ **Constraints are given as follow-**

1. **C29=0** linked to machine run time for Machine 5 for Part 1 justifying in setup time that Machine 5 does not operate for Part 1 due to which it has been put to zero.
2. **C40=C4** justifies those total parts produced and demands of units per part should be equal.
3. **M25 ≤ L25** where constraint M25 justifies that Total time to produce a part + to the total setup time should be less than or equal to the total production hours for whole week.
4. **0 ≤ N25 ≤48** means that overtime should be either to 0 or 48 or lies between the range but does not exceed the range of 48 or go below 0.

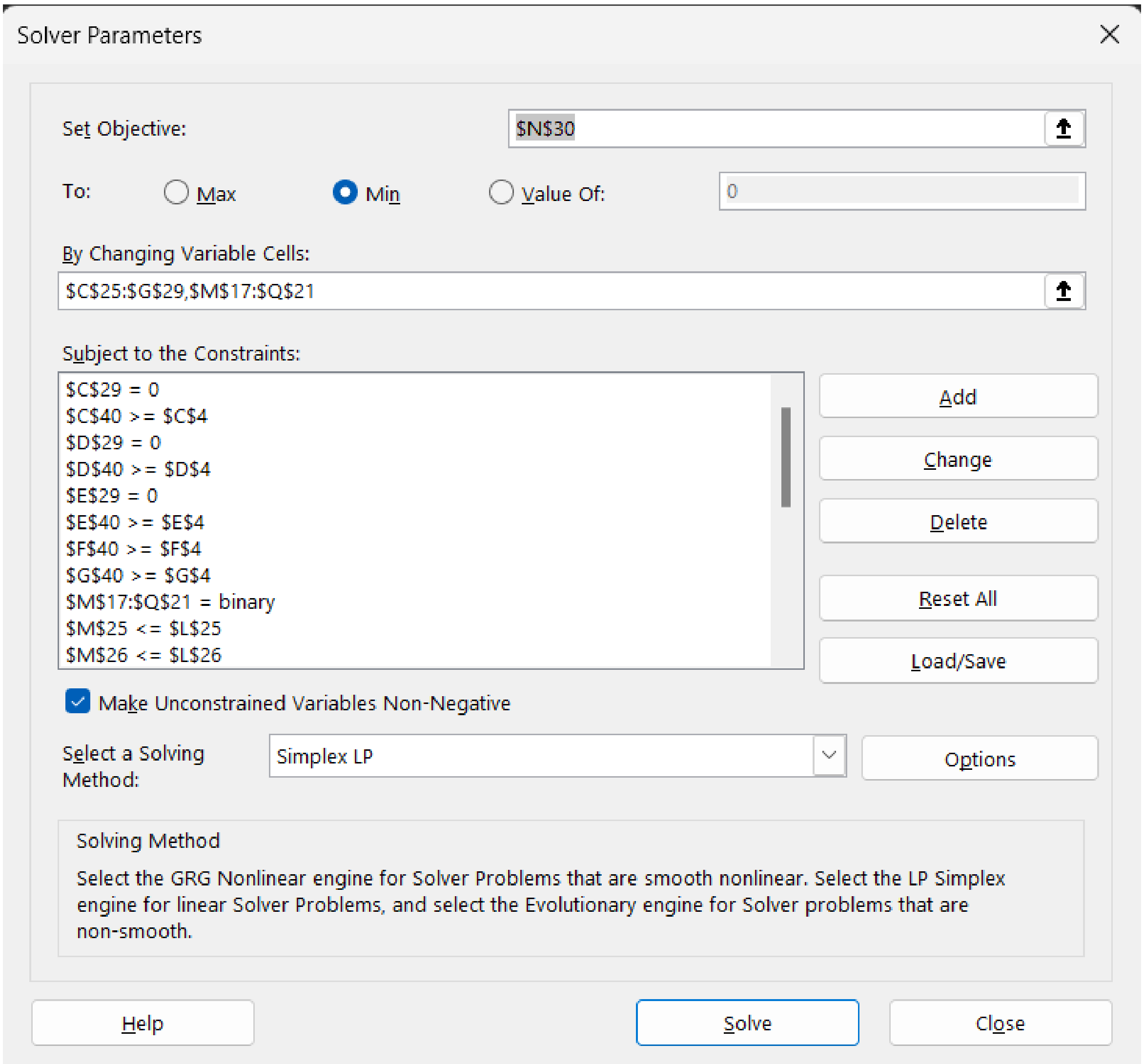

Figure: Solver with conditions and constraint

5. **M7 to Q21** is a binary table created to receive the output of 1 if machine is working and output of 0, if machine is not working. (given in Table 11.

Machine number	Part 1	Part 2	Part 3	Part 4	Part 5
Machine 1	1	0	0	1	0
Machine 2	1	0	0	0	0
Machine 3	0	1	0	0	0
Machine 4	0	1	1	0	0
Machine 5	0	0	0	0	1

Table 12: Binary Table

6. T17 to X21 is a negative constraint table created to apply the condition that if the binary output is 1 then the multiplication of binary output per part per machine to 168 (i.e. sum of total production hours in weekdays and total production hours in weekends) and will be subtracted to machine run time to justify whether machine is working or not.

Machine number	Part 1	Part 2	Part 3	Part 4	Part 5
Machine 1	118.5641	0	0	65.4358974	0
Machine 2	57.831502	0	0	0	0
Machine 3	0	34.4040404	0	0	0
Machine 4	0	126.6666667	61.33333333	0	0
Machine 5	0	0	0	-3.553E-15	68

Table 13: Negative Constraints Table

- **Step 7** After operating the excel solver within the following constraints, it is found that the total overtime for Week 1 is 119.76 and with that overtime Total demands required for every part is fulfilled accordingly.

{Binary Value} *168-[Machine Runtime] =

→ Positive Answer → Give Binary = 1

→ Negative Answer → Give Binary = 0

Total Time Machine Run	Part 1	Part 2	Part 3	Part 4	Part 5	Total time to produce
Machine 1	49.4358974	0	0	102.5641026	0	152.00
Machine 2	110.168498	0	0	0	0	110.17
Machine 3	0	133.5959596	0	0	0	133.60
Machine 4	0	41.33333333	106.6666667	0	0	148.00
Machine 5	0	0	0	0	100	100.00
						643.76

Table 14: Fulfilled Machine Run time per part per machine

Total Aval time (Mon -Fri)	Overtime Hours (Sat & Sun)	Total Production Hours Available	Total time to produce + Total Setup time	Total Overtime
120	48	168	168.00	48.00
120	48	168	120.17	0.17
120	48	168	143.60	23.60
120	48	168	168.00	48.00
120	48	168	120.00	0.00
			719.76	119.76

Table 15: Fulfilled Total Overtime

Unit Produced	Part 1	Part 2	Part 3	Part 4	Part 5
Machine 1	1186	0	0	4000	0
Machine 2	2314	0	0	0	0
Machine 3	0	2204	0	0	0
Machine 4	0	796	4000	0	0
Machine 5	0	0	0	0	3000
Total Product Produced	3500	3000	4000	4000	3000

Table 16: Product Produced by each Machine.

- **Step 8-** Above mentioned procedures including same constraints and same solver setup will be implemented for the following 12 other weeks.

Problem 3. Whenever overtime production needs to be scheduled, the traditional practice has been to schedule it on machines that are most efficient for the part being produced. This has often led to uneven overtime assignment in the sense that long hours of overtimes are scheduled on one or two machines while other machines remained idle. While this resulted in lower total overtime paid to production personnel, it often resulted in higher overall costs because of the overtime costs of the required support personnel such as administrative assistants, electricians, material handlers and quality control technicians. Their presence is necessary as long as production is in process, irrespective of the number of machines operating. Tom wondered if it would be more economical to schedule production on more machines over the weekend and minimize the total duration for which overtime production takes place. Modify your model to minimize the total duration of overtime production (i.e., maximum of the overtimes on all machines) rather than the sum of overtimes on all machines? Compare the optimal production schedule obtained with the new objective with that for question 1 and then discuss the nature of changes in the optimal solution.

Sol: In the previous model, the attempt was to reduce total machine hours of overtime across all machines. However, as per the question we need to minimize the maximum overtime among all the 5 machines rather than minimizing the total overtime of all the machines. Here the primary objective is to reduce the maximum overtime hours across all machines. This means ensuring that no single machine has excessive overtime, and scheduling production on more machines over the weekend. Therefore, to achieve the required solution the required modifications have been done in excel solver.

Total Time Machine Run	Part 1	Part 2	Part 3	Part 4	Part 5	Total time to produce
Machine 1	54.49	0.00	0.00	76.70	0.00	131.20
Machine 2	104.39	24.81	0.00	0.00	0.00	129.20
Machine 3	0.00	137.20	0.00	0.00	0.00	137.20
Machine 4	0.00	20.53	106.67	0.00	0.00	127.20
Machine 5	0.00	0.00	0.00	25.86	93.33	119.20
						643.98

Table 17: Total Machine Run Time

Total Avl time (Mon - Fri)	Overtime Hours (Sat & Sun)	Total Production Hours Available	Total time to produce + Total Setup time	Total Overtime
120	48	168	147.20	27.20
120	48	168	147.20	27.20
120	48	168	147.20	27.20
120	48	168	147.20	27.20
120	48	168	147.20	27.20
			735.98	135.98
				27.20

Table 18: Total Overtime

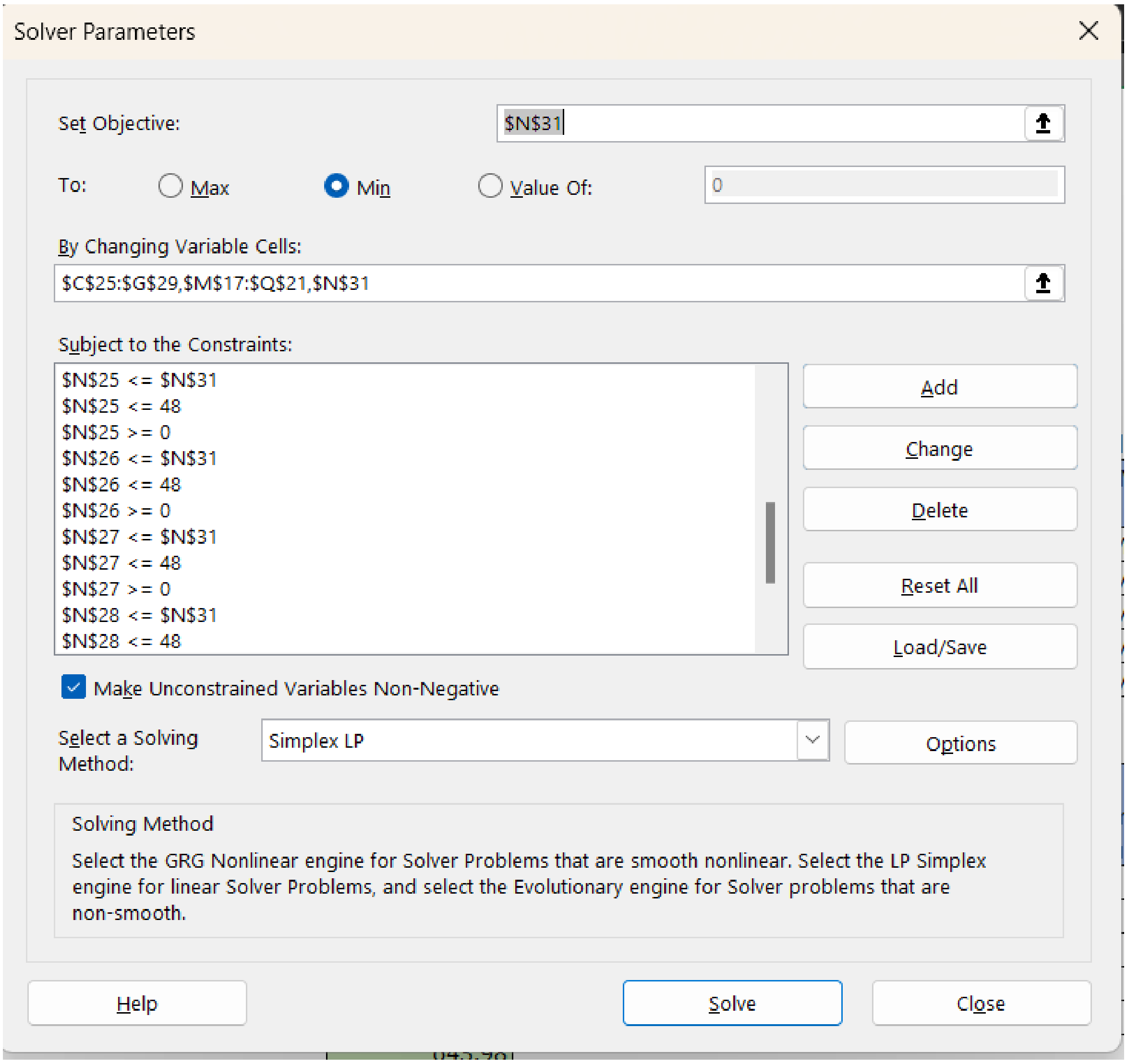

Figure: Solver with constraint and other parameters

Here for the objective function we have the equation, Minimize Z= $\sum_{i=1,\, t=1}^{i=5,\, t=12}(O_{it})$, which is represented by the cell N31, where we are minimizing the maximum overtime of all 5 machines.

For the constraints, we have similar constraints as in Question 2, with one additional constraint i.e. $OT_j \leq OT_{Max}$ which means, the overtime for each machine should be less than or equal to the maximum overtime of all the 5 machines.

With the above-mentioned objective function and constraints, we have got the value of 27.20 as per our Excel solver which is the minimized overtime production on all machines.

Problem 4: Modify your model to minimize the total cost of overtime for production and support personnel, assuming that the cost of scheduling overtime on each machine is $30 per hour and the cost of support personnel during overtime is $40 per hour.

The objective function of this problem is to minimize the overall cost associated with overtime for production and support personnel. There are two types of costs involved: one is the cost of scheduling overtime on each machine, amounting to $30 per hour, and the other is the cost of support personnel during the overtime period, which is $40 per hour. The total overtime cost for each machine (OT_j) is calculated by multiplying the machine's overtime period by $30. It's important to note that OT_max represents the maximum time a worker is available in the factory. So, the total support personnel cost is determined by multiplying the maximum allowable overtime period (OT_max) by $40.
So with the above data, we get the objective function value by adding total overtime cost for each machine and total cost of support personnel.

Objective Function: The objective of this problem is to minimize the total cost, represented by the objective function Z. The cost consists of 2 parts:

Minimize $Z = (\sum_{j=1}^{5} OT_j * 30) + (OT_{Max} * 40)$

Regular Overtime Costs ($\sum_{j=1}^{5} OT_j$):
The first term in the objective function represents the regular overtime costs for each machine (OT_j) multiplied by a cost factor of $30.

Cost to support personnel (OT_{Max}):
The second term represents the maximum overtime cost needed for the support personnel. multiplied by a cost factor of $40.

The decision variables and constraints are similar to Question 2.

Total cost = total overtime cost + total support costs = 4079.4 + 1088 = 5167.4.

Problem 5: At present, the weekend preventive maintenance effectively resets the machines so that a new setup is required to start each week's production (question 1). Tom and the maintenance supervisor developed a method by which the routine maintenance can be performed without disturbing its setup. Modify your model to take advantage of the initial setup on a machine at the beginning of a week. Assume that machines 1 through 5 are setup to produce parts 1, 2, 5, 3 and 4 respectively, at the start of week 1.

The objective function in this optimization problem is to minimize the overall overtime for all five machines which is like question 2. Initially, each machine is set up with a specific part, and a table outlines the setup times for each machine with its corresponding part.

Machine number	Part Number
Machine 1	1
Machine 2	2
Machine 3	5
Machine 4	3
Machine 5	4

The value of 0 is entered in the table where the setup time is not considered, the rest of the table has remained unchanged.

Setup Times of parts per machines

Machine Number	Part 1	Part 2	Part 3	Part 4	Part 5	Setup Time (1)	Setup Time (2)	Total Setup Time (1+2)
Machine 1	0	0	0	8	0	0	0	0
Machine 2	10	0	0	0	0	0	0	0
Machine 3	0	10	0	0	0	10	0	10
Machine 4	0	8	0	0	0	8	0	8
Machine 5	0	0	0	0	20	0	20	20

For the optimization process using Excel Solver, the objective function is represented by the cell N30 as the goal is to minimize the total overtime across all machines. After solving the problem with Excel Solver, the resulting value for the objective function is found to be 88.37.

5 Numerical Results of each week:

Q.2)

Week 1	119.76
Week 2	92.33
Week 3	25.71
Week 4	93.78
Week 5	100.24
Week 6	75.87
Week 7	76.4
Week 8	122.78
Week 9	31.08
Week 10	15.11
Week 11	Infeasible Solution
Week 12	93.67

Q.3)

Week Number	Total Overtime
Week 1	27.20
Week 2	22.17
Week 3	8.76
Week 4	22.15
Week 5	23.15
Week 6	18.08
Week 7	17.81
Week 8	27.67
Week 9	21.09
Week 10	19.64
Week 11	Infeasible Solution
Week 12	22.17

Q.4)

Week Number	Overtime Cost	Support Cost	Total Cost
Week 1	3688.618881	1469.463869	5158.082751
Week 2	2845.670996	1314.285714	4159.95671
Week 3	784.86	448.48	1233.34
Week 4	3323.155	886.1746668	4209.329667
Week 5	3472.520198	926.0053862	4398.525584
Week 6	2395.611888	910.02331	3305.635198
Week 7	2377.15035	795.1515152	3172.301865
Week 8	4150.658565	1106.842284	5257.500849
Week 9	932.3486038	604.4444444	1536.793048
Week 10	780.4449437	208.1186516	988.5635953
Week 11	Infeasible Solution		
Week 12	2845.23	1314	4159.23

Q.5)

Week 1	**Total Overtime**	88.37

6. Discussion and concluding remarks:

6.1 Managerial Insights

1. Enhancement of Quality:

• Put your attention on ongoing development to progressively reduce the amount of defects.
• To improve quality, examine and modify procedures on a regular basis depending on yield factors.

2. Capacity Utilization:

- Investigate methods, like resolving quality concerns and streamlining procedures, to increase effective capacity.

• Keep an eye on overtime utilization and strive to lower it through raising yields and efficient capacity.

3. Maximizing Scheduling for Production:

• To assign production effectively, use optimization algorithms to implement systematic scheduling procedures.
• To improve production planning and reduce the need for trial-and-error modifications, use historical data and demand estimates.

4. Efficiency of Machine Setup:

• Make an investment in technology or techniques that shorten setup times, hence enabling more adaptable production schedules.
• Take into account retraining staff members to operate a variety of machines to lessen reliance on specialized configurations.

5. Impact of Inventory Policy:

•Evaluate the impact of the no-inventory policy on production schedules and explore potential benefits of carrying limited inventory, especially for high-demand items.
•Collaborate with maintenance to optimize routine maintenance schedules without disrupting setups.

By addressing these insights, Falcon Die Casting Company can work towards improving its production scheduling, enhancing quality, and optimizing resource utilization.

6.2. Conclusions:

Based on the given problem description, several conclusions and recommendations can be drawn for Falcon Die Casting Company:

1. **Quality Improvement is Critical:** The business must prioritize and intensify its efforts to raise the caliber of its output. Long-term profitability and satisfying client requirements depend heavily on addressing flaws and raising yield variables.

2. **Optimizing Capacity Effectively:**
• Optimizing effective capacity should be the company's primary goal in order to efficiently meet long-term demand. This entails fixing problems with quality, improving production procedures, and taking technology advancements into account.

3. **Strategic Overtime Utilization:** The organization recognizes that it must produce overtime until yields improve, given the current limits. To avoid overtime while fulfilling customer needs and production targets, strategic planning is necessary.

4. **Systematic Scheduling strategy**: The requirement for efficiency and optimization is reflected in Tom Kelley's advocacy of a systematic scheduling strategy. Using sophisticated scheduling tools or algorithms can result in more efficient production.

5. Inventory Policy's Effect:

One distinctive feature of Falcon Die Casting Company is their philosophy of having no inventory. It is important to closely monitor how this policy affects machine utilization and production schedules. For products with high demand, limited inventory may be taken into account.

6. Cooperation and Interaction:

• It is imperative that production planning, quality control, and maintenance work together more closely and communicate more effectively. Coordinated efforts guarantee improved overall efficiency, expedited issue resolution, and streamlined processes.

7. Employee Training and Cross-Training: Putting money into employee training programs, particularly those that involve cross-training, can help to increase machine assignments' and setup times' flexibility. Multiple duties can be handled by well-trained workers, which reduces reliance on particular arrangements.

8. Culture of continual development: Long-term success depends on establishing a culture of continual development. reviewing procedures on a regular basis.

9. The Wise Use of Time:

• Strategic planning is crucial because working overtime results in extra expenses. Cost savings will come from identifying and reducing overtime through effective scheduling and resolving the underlying causes of quality problems.

10. Scenario Investigation:

• Falcon Die Casting Company have to think about investigating a range of situations, including fluctuations in demand, the launch of new products, and technological advancements. By simulating these scenarios, one can gain insight into the adaptability and resilience of the firm.

7. Future Work:

7.1 Propose possible further scenarios:

Demand Variability:

- Consider scenarios with higher demand variability to test the robustness of the production scheduling system. Evaluate how the system responds to sudden increases or decreases in demand.

Introduction of a New part:

- Examine possible introduction scenarios for new die-cast parts. Analyze the effects on quality control, machine use, and production schedules.

Programs for employee training:

- Put employee training programs into action and run scenarios to see how well-trained employees affect setup times, production schedules, and overall productivity.

Quality Improvement Initiatives:

- Introduce scenarios where the company accelerates its quality improvement initiatives. Evaluate the impact on defect levels, yield factors, and overall customer satisfaction.

Inventory Policy Modifications:

- Test scenarios with adjustments to the no-inventory policy. Explore the impact of carrying minimal finished goods inventory for certain high-demand items on production schedules and customer satisfaction.

Disruptions to suppliers or logistics:

- Play out scenarios in which the logistics or supply chain are disrupted. Examine the company's capacity for flexibility in modifying production schedules to lessen the effects of such alterations.

7.2 Discuss New Data and Further Possible Analysis:

The potential areas for further analysis using new data and different analytical approaches:

1. **Granular Demand Data:** Obtain weekly demand data for individual parts instead of aggregated data for all five. This would allow for more precise forecasting and production planning for each machine.
2. **Machine Performance and Yield Analysis:** Collect and analyse machine-specific data, including setup times, cycle times, and downtime reasons. This would help identify bottlenecks and optimize machine utilization.
3. **Scheduling and Optimization:** Explore advanced scheduling algorithms, such as genetic algorithms or constraint programming, to optimize production plans considering machine capacities, setup times, and yield rates. Analyze the cost-effectiveness of overtime production versus capacity expansion or outsourcing options.